ANNEX L

Methodology for Estimating N_2O Emissions from Agricultural Soil Management

Nitrous oxide (N_2O) emissions from agricultural soil management covers activities that add nitrogen (N) to soils, and thereby enhance natural emissions of N_2O. The IPCC methodology (IPCC/UNEP/OECD/IEA 1997, IPCC 2000), which is followed, divides this source category into three components: (1) direct N_2O emissions from managed soils; (2) direct N_2O emissions from pasture, range, and paddock livestock manure; and (3) indirect N_2O emissions from soils induced by applications of nitrogen.

There are four steps in estimating N_2O emissions from agricultural soil management. First, the activity data are derived for each of the three components. Note that some of the data used in the first component are also used in the third component. In the second, third, and fourth steps, N_2O emissions from each of the three components are estimated. The remainder of this annex describes these steps, and data used in these steps, in detail.

Step 1: Derive Activity Data

The activity data for this source category are annual amounts of nitrogen added to soils for each relevant activity, except for histosol cultivation, for which the activity data are annual histosol areas cultivated.[1] The activity data are derived from statistics, such as fertilizer consumption data or livestock population data, and various factors used to convert these statistics to annual amounts of nitrogen, such as fertilizer nitrogen contents or livestock excretion rates. Activity data were derived for each of the three components, as described below.

Step 1a. Direct N_2O Emissions from Managed Soils.

The activity data for this component include: a) the amount of synthetic and organic commercial fertilizer nitrogen applied annually, b) the amount of livestock manure nitrogen applied annually through both daily spread operations and the eventual application of manure that had been stored in manure management systems, c) the amount of sewage sludge nitrogen applied annually, d) the amount of aboveground biomass nitrogen in nitrogen-fixing crops produced annually, e) the amount of nitrogen in crop residues applied to soils annually, and f) the area of histosols cultivated annually.

Application of synthetic and organic commercial fertilizer: Annual commercial fertilizer consumption data for the United States were taken from annual publications of synthetic and organic fertilizer statistics (TVA 1991, 1992a, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999). These data were manipulated in several ways to derive the activity data needed for the inventory. First, the manure and sewage sludge portions of the organic fertilizers were subtracted from the total organic fertilizer consumption data because these nitrogen additions are accounted for under "manure application" and "sewage sludge application."[2] Second, the organic fertilizer data, which are recorded in mass units of fertilizer, had to be converted to mass units of nitrogen by multiplying by the average organic fertilizer nitrogen contents provided in the annual fertilizer publications. These nitrogen contents are weighted average values, so they vary from year-to-year (ranging from 2.3 percent to 3.9 percent over the period 1990 through 1999). The synthetic fertilizer data are recorded in units of nitrogen, so these data did not need to be converted. Lastly, both the synthetic and organic fertilizer consumption data are recorded in "fertilizer year" totals (i.e., July to June), therefore the data was converted to calendar year totals. This was done by assuming that approximately 35 percent of fertilizer usage occurred from July to December, and 65 percent from January to June (TVA 1992b). July to December values were not available for calendar year 1999, so a "least squares line" statistical extrapolation using the previous ten years of data was used to arrive at an approximate value. Annual

[1] Histosols are soils with a high organic carbon content.

[2] Organic fertilizers included in these publications are manure, compost, dried blood, sewage sludge, tankage, and "other." (Tankage is dried animal residue, usually freed from fat and gelatin). The manure and sewage sludge used as commercial fertilizer are accounted for elsewhere, so these were subtracted from the organic fertilizer statistics to avoid double counting.

consumption of commercial fertilizers—synthetic and non-manure/non-sewage organic—in units of nitrogen and on a calendar year basis are presented in Table L-1.

Application of livestock manure: To estimate the amount of livestock manure nitrogen applied to soils, it was assumed that all of the manure produced by livestock would be applied to soils with two exceptions. These exceptions were: (1) the portion of poultry manure that is used as a feed supplement for ruminants, and (2) the manure that is deposited on soils by livestock on pasture, range, and paddock. In other words, all of the manure that is managed, except the portion of poultry manure that is used as a feed supplement, is assumed to be applied to soils. The amount of managed manure for each livestock type was calculated by determining the population of animals that were on feedlots or otherwise housed in order to collect and manage the manure. In some instances, the number of animals in managed systems was determined by subtracting the number of animals in pasture, range, and paddock from the total animal population for a particular animal type.

Annual animal population data for all livestock types, except horses and goats, were obtained from the USDA National Agricultural Statistics Service (USDA 1994b-c, 1995a-b, 1998a, 1998c, 1999a-c, 2000a-g). Horse population data were obtained from the FAOSTAT database (FAO 2000). Goat population data were obtained from the Census of Agriculture (USDA 1999d). Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the Census of Agriculture (USDA 1999e).

Information regarding the percentage of manure handled using various manure management systems for dairy cattle, beef cattle, and sheep was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, National Agricultural Statistics Service, and other experts (Poe et al. 1999, Anderson 2000, Deal 2000, Johnson 2000, Miller 2000, Milton 2000, Stettler 2000, Sweeten 2000, Wright 2000). Information regarding the percentage of manure handled using various manure management systems for swine, poultry, goats, and horses was obtained from Safley et al. (1992). A more detailed discussion of manure management system usage is provided in Annex K under Manure Management.

Once the animal populations for each livestock type and management system were estimated, these populations were then multiplied by an average animal mass constant (USDA 1996a, USDA 1998c, ASAE 1999, Safley 2000) to derive total animal mass for each animal type in each management system. Total Kjeldahl nitrogen[3] excreted per year for each livestock type and management system was then calculated using daily rates of nitrogen excretion per unit of animal mass (USDA 1996a, ASAE 1999). The total poultry manure nitrogen in managed systems was reduced by the amount assumed to be used as a feed supplement (i.e., 4.2 percent of the managed poultry manure; Carpenter 1992). The annual amounts of Kjeldahl nitrogen were then summed over all livestock types and management systems to derive estimates of the annual manure nitrogen applied to soils (Table L-2).

Application of sewage sludge: Data collected by the EPA were used to derive estimates of annual nitrogen additions from land application of sewage sludge. Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works. Based on a 1988 questionnaire returned from 600 publicly owned treatment works (POTWs), the EPA estimated that 5.4 million metric tons of dry sewage sludge were generated by POTWs in the United States in that year (EPA 1993). Of this total, 43.7 percent was applied to land, including agricultural applications, compost manufacture, forest land application, the reclamation of mining areas, and other forms of surface disposal. An additional 33.9 percent of the total generated was disposed in landfills, 16.1 percent was incinerated, and 6.3 percent was dumped into the oceans (EPA 1993). In 1997, the EPA conducted a nationwide state-by-state study that estimated that approximately 7 million metric tons of dry sewage sludge were generated by 12,000 POTWs (Bastian 1999). The same study concluded that 54 percent of sewage sludge generated that year was applied to land. Sewage sludge production increased between 1988 and 1997 due to increases in the number of treatment plants and the magnitude of industrial wastewater treated, as well as changes in sewage treatment techniques. The proportion of sewage sludge applied to land increased due to the passage of legislation in 1989 that banned all ocean dumping of sewage, as well as stricter laws regulating the use of landfills for sewage disposal (Bastian 1999).

Annual estimates of sewage sludge nitrogen applied to land for the 1990 to 1999 period were derived through the following process. To estimate annual amounts of dry sewage sludge applied to land in 1990 through

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[3] Total Kjeldahl nitrogen is a measure of organically bound nitrogen and ammonia nitrogen in both the solid and liquid wastes.

1997, the 1988 and 1997 data for sewage sludge production and percent land applied were linearly interpolated. Since 1997, growth in annual production and the percent land applied is believed to have leveled off (Bastian 1999), so the 1998 and 1999 estimates of sewage production and percent land applied were held constant at 1997 levels. Between 1 and 6 percent of dry weight sewage sludge is nitrogen, both in organic and inorganic form (National Research Council 1996). Therefore, to covert from metric ton of dry sludge to metric ton of nitrogen, an average 4 percent nitrogen content was used. Final estimates of annual land application of sewage sludge nitrogen are presented in Table L-1.

Production of nitrogen-fixing crops: Annual production statistics for beans, pulses, and alfalfa were taken from U.S. Department of Agriculture crop production reports (USDA 1994a, 1997, 1998b, 1999f, 2000i). Annual production statistics for the remaining nitrogen-fixing crops (i.e., the major non-alfalfa forage crops, specifically red clover, white clover, birdsfoot trefoil, arrowleaf clover, and crimson clover) were derived from information in a book on forage crops (Taylor and Smith 1995, Pederson 1995, Beuselinck and Grant 1995, Hoveland and Evers 1995), and personal communications with forage experts (Cropper 2000, Evers 2000, Gerrish 2000, Hoveland 2000, and Pederson 2000).

The production statistics for beans, pulses, and alfalfa were in tons of product, which needed to be converted to tons of aboveground biomass nitrogen. This was done by multiplying the production statistics by one plus the aboveground residue to crop product mass ratios, dry matter fractions, and nitrogen contents. The residue to crop product mass ratios for all beans and pulses, and the dry matter content for soybeans, were obtained from Strehler and Stützle (1987). The dry matter content for peanuts was obtained through personal communications with Jen Ketzis (1999), who accessed Cornell University's Department of Animal Science's computer model, Cornell Net Carbohydrate and Protein System. The dry matter content for soybeans was used for all other beans and pulses. The dry matter content for alfalfa was obtained through personal communications with Karkosh (2000). The IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997) was used for all beans, pulses, and alfalfa.[4]

The production statistics for the non-alfalfa forage crops were derived by multiplying estimates of areas planted by estimates of annual yields, in dry matter mass units. These derived production statistics were then converted to units of nitrogen by applying the IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997).

The final estimates of annual aboveground biomass production, in units of nitrogen, are presented in Table L-3. The residue to crop product mass ratios and dry matter fractions used in these calculations are presented in Table L-6.

Application of crop residue: It was assumed that 90 percent of residues from corn, wheat, barley, sorghum, oats, rye, millet, soybeans, peanuts, and other beans and pulses are either plowed under or left on the field (Karkosh 2000).[5] It was also assumed that 100 percent of unburned rice residue is applied to soils.[6]

The derivation of residue nitrogen activity data was very similar to the derivation of nitrogen-fixing crop activity data. Crop production statistics were multiplied by aboveground residue to crop product mass ratios, residue dry matter fractions, residue nitrogen contents, and the fraction of residues applied to soils. Annual production statistics were taken from U.S. Department of Agriculture (USDA 1994a, 1997, 1998b, 1999f, 2000i). Residue to crop product ratios for all crops were obtained from Strehler and Stützle (1987). Dry matter contents for wheat, rice, corn, and barley residue were obtained from Turn et al. (1997). Soybean and millet residue dry matter contents were obtained from Strehler and Stützle (1987). Peanut, sorghum, oat, and rye residue dry matter contents were obtained through personal communications with Jen Ketzis (1999), who accessed Cornell University's Department of Animal Science's computer model, Cornell Net Carbohydrate and Protein System. The residue nitrogen contents for wheat, rice, corn, and barley are from Turn et al. (1997). The nitrogen content of soybean

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[4] This nitrogen content likely overestimates for the residue portion of the aboveground biomass of the beans and pulses. Also, the dry matter fractions used for beans and pulses were taken from literature on crop residues, and so may under estimate the product portion of the aboveground biomass. These data will be refined in future inventories.

[5] Although the mode of residue application would most likely affect the magnitude of emissions, a methodology for estimating N_2O emissions for these two practices separately has not been developed.

[6] Some of the rice residue may be used for other purposes, such as for biofuel or livestock bedding material. Research to obtain more detailed information regarding final disposition of rice residue, as well as the residue of other crops, will be undertaken for future inventories.

residue is from Barnard and Kristoferson (1985), the nitrogen contents of peanut, sorghum, oat, and rye residue are from Ketzis (1999), and the nitrogen content of millet residue is from Strehler and Stützle (1987). Estimates of the amounts of rice residue burned annually were derived using information obtained from agricultural extension agents in each of the rice-growing states (see Rice Cultivation section of Agriculture Chapter for more detail).

The final estimates of residue applied to soil, in units of nitrogen (N), are presented in Table L-4. The residue to crop product mass ratios, residue dry matter fractions, and residue nitrogen contents used in these calculations are presented in Table L- 6.

Cultivation of histosols: Statistics on the areas of histosols cultivated in 1982, 1992, and 1997 were obtained from the USDA's 1992 and 1997 National Resources Inventories (USDA 1994d and 2000h, as cited in Paustian 1999 and Sperow 2000, respectively).[7] These areas were linearly interpolated to obtain estimates for 1990 through 1997, and linearly extrapolated to obtain area estimates for 1998 and 1999 (Table L-5).

Step 1b. Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure.

Estimates of N_2O emissions from this component were based on livestock manure that is not managed in manure management systems, but instead is deposited directly on soils by animals in pasture, range, and paddock. The livestock included in this component were: dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses.

Dairy Cattle: Information regarding dairy farm grazing was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, and other experts (Poe et al. 1999, Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000). Because grazing operations are typically related to the number of animals on a farm, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used in conjunction with the state data obtained from personal communications to determine the percentage of total dairy cattle that graze. An overall percent of dairy waste that is deposited in pasture, range, and paddock was developed for each region of the United States. This percentage was applied to the total annual dairy cow and heifer state population data for 1990 through 1999, which were obtained from the USDA National Agricultural Statistics Service (USDA 1995a, 1999a, 2000a,b).

Beef Cattle: To determine the population of beef cattle that are on pasture, range, and paddock, the following assumptions were made: 1) beef cows, bulls, and calves were not housed on feedlots; 2) a portion of heifers and steers were on feedlots; and 3) all beef cattle that were not housed on feedlots were located on pasture, range, and paddock (i.e., total population minus population on feedlots equals population of pasture, range, and paddock) (Milton 2000). Information regarding the percentage of heifers and steers on feedlots was obtained from USDA personnel (Milton 2000) and used in conjunction with USDA National Agricultural Statistics Service population data (USDA 1995a, 1999a, 2000a,b) to determine the population of steers and heifers on pasture, range, and paddock.

Swine: Based on the assumption that smaller facilities are less likely to utilize manure management systems, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used to determine the percentage of all swine whose manure is not managed (i.e., the percentage on pasture, range, and paddock). These percentages were applied to the average of the quarterly USDA National Agricultural Statistics Service population data for swine (USDA 1994b, 1998a, 2000e) to determine the population of swine on pasture, range, and paddock.

Sheep: It was assumed that all sheep and lamb manure not deposited on feedlots was deposited on pasture, range, and paddock (Anderson 2000). Sheep population data were obtained from the USDA National Agricultural Statistics Service (USDA 1994c, 1999c, 2000g). However, population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 1999 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep and lamb "on feed" were not necessarily on "feedlots"; they may have been on pasture/crop residue supplemented by feed. Data for those feedlot animals versus pasture/crop residue were provided only for lamb in 1993. To calculate the

[7] The estimates of cultivated histosol areas are uncertain because they were derived from a natural resource inventory that was not explicitly designed as a soil survey. However, these areas are consistent with those used in the organic soils component of the Land-Use Change and Forestry Chapter. These area statistics will be researched further in future U.S. Inventories.

populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: It was assumed that 92 percent of goat manure was deposited on pasture, range, and paddock (Safley et al. 1992). Annual goat population data by state were available for only 1992 and 1997 (USDA 1999d). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 1999. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Poultry: It was assumed that one percent of poultry manure was deposited on pasture, range, and paddock (Safley et al. 1992). Poultry population data were obtained from USDA National Agricultural Statistics Service (USDA 1995b, 1998a, 1999b, 2000c, 2000d, 2000f). The annual population data for boilers and turkeys were adjusted for turnover (i.e., slaughter) rate (Lange 2000).

Horses: It was assumed that 92 percent of horse manure was deposited on pasture, range, and paddock (Safley et al. 1992). Horse population data were obtained from the FAOSTAT database (FAO 2000).

For each animal type, the population of animals within pasture, range, and paddock systems was multiplied by an average animal mass constant (USDA 1996, ASAE 1999, USDA 1998d, Safley 2000) to derive total animal mass for each animal type. Total Kjeldahl nitrogen excreted per year was then calculated for each animal type using daily rates of nitrogen excretion per unit of animal mass (USDA 1996, ASAE 1999). Annual nitrogen excretion was then summed over all animal types to yield total nitrogen in pasture, range, and paddock manure (Table L-2).

Step 1c. Indirect N_2O Emissions from Soils Induced by Applications of Nitrogen.

This component accounts for N_2O that is emitted indirectly from nitrogen applied as commercial fertilizer, sewage sludge, and livestock manure. Through volatilization, some of this nitrogen enters the atmosphere as NH_3 and NO_x, and subsequently returns to soils through atmospheric deposition, thereby enhancing N_2O production. Additional nitrogen is lost from soils through leaching and runoff, and enters groundwater and surface water systems, from which a portion is emitted as N_2O. These two indirect emission pathways are treated separately, although the activity data used are identical. The activity data for commercial fertilizer and sewage sludge are the same as those used in the calculation of direct emissions from managed soils (Table L-1). The activity data for livestock manure are different from those used in other calculations. Here, total livestock manure (i.e., the sum of managed manure and manure in pasture, range, and paddock) is used. These data are presented in Table L-2.

Table L-1: Commercial Fertilizer Consumption & Land Application of Sewage Sludge (Gg N)

Fertilizer Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Synthetic	10,105	10,262	10,324	10,718	11,162	10,798	11,158	11,172	11,187	11,262
Other Organics*	3	6	6	6	6	8	10	12	12	11
Sewage Sludge	106	112	118	124	131	137	144	151	151	151

* Excludes manure and sewage sludge used as commercial fertilizer.

Table L-2: Livestock Manure Nitrogen (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Applied to Soils	2,610	2,680	2,688	2,723	2,748	2,740	2,746	2,803	2,833	2,832
Pasture, Range, & Paddock	4,173	4,192	4,295	4,339	4,453	4,513	4,507	4,375	4,285	4,246
Total Manure	6,815	6,905	7,016	7,096	7,227	7,258	7,290	7,215	7,155	7,115

Table L-3: Aboveground Biomass Nitrogen in Nitrogen-Fixing Crops (Gg)

Crop Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Soybeans	4,241	4,374	4,823	4,117	5,538	4,788	5,241	5,921	6,036	5,820
Peanuts	84	115	100	79	99	81	86	83	93	91
Dry Edible Beans	119	124	83	80	106	113	102	108	112	122
Dry Edible Peas	7	11	8	10	7	14	8	17	18	15
Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+
Lentils	5	8	6	7	7	8	5	9	7	9
Wrinkled Seed Peas	3	3	2	3	2	3	2	2	2	2
Alfalfa	1,730	1,729	1,642	1,666	1,687	1,753	1,647	1,641	1,708	1,731
Red Clover	513	513	513	513	513	513	513	513	513	513
White Clover	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735
Birdsfoot Trefoil	99	99	99	99	99	99	99	99	99	99
Arrowleaf Clover	67	67	67	65	63	61	58	56	54	52
Crimson Clover	21	21	21	19	18	17	16	14	13	12
Total	**9,624**	**9,799**	**10,098**	**9,394**	**10,874**	**10,184**	**10,512**	**11,198**	**11,389**	**11,200**

+ Less than 0.5 Gg nitrogen.
Note: Totals may not sum due to independent rounding.

Table L-4: Nitrogen in Crop Residues Applied to Soils (Gg)

Product Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Corn	957	902	1,143	765	1,219	890	1,121	1,130	1,177	1,139
Wheat	501	364	453	440	426	401	418	456	468	423
Barley	71	78	77	67	63	61	67	63	59	47
Sorghum	180	184	275	168	206	145	253	205	164	187
Oats	39	27	32	23	25	18	17	19	18	16
Rye	2	2	2	2	2	2	1	1	2	2
Millet	3	3	3	3	3	3	3	3	3	3
Rice	54	56	64	55	69	62	59	66	70	79
Soybeans	1,982	2,045	2,254	1,926	2,633	2,241	2,452	2,807	2,821	2,720
Peanuts	13	18	16	13	16	13	14	13	15	14
Dry Edible Beans	15	16	10	10	13	14	13	14	14	15
Dry Edible Peas	1	1	1	1	1	2	1	2	2	2
Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+
Lentils	1	1	1	1	1	1	1	1	1	1
Wrinkled Seed Peas	+	+	+	+	+	+	+	+	+	+
Total	**3,821**	**3,696**	**4,332**	**3,473**	**4,678**	**3,850**	**4,420**	**4,781**	**4,814**	**4,649**

+ Less than 0.5 Gg nitrogen.
Note: Totals may not sum due to independent rounding.

Table L-5: Cultivated Histosol Area (Thousand Hectares)

Year	Area
1990	1,013
1991	1,005
1992	998
1993	994
1994	991
1995	987
1996	984
1997	980
1998	977
1999	973

Table L-6: Key Assumptions for Nitrogen-Fixing Crop Production and Crop Residue Application

Crop	Residue/Crop Ratio	Residue Dry Matter Fraction	Residue Nitrogen Fraction
Soybeans	2.1	0.87	0.023
Peanuts	1.0	0.86	0.0106
Dry Edible Beans	2.1	0.87	0.0062
Dry Edible Peas	1.5	0.87	0.0062
Austrian Winter Peas	1.5	0.87	0.0062
Lentils	2.1	0.87	0.0062
Wrinkled Seed Peas	1.5	0.87	0.0062
Alfalfa	0	0.85	NA
Corn	1.0	0.91	0.0058
Wheat	1.3	0.93	0.0062
Barley	1.2	0.93	0.0077
Sorghum	1.4	0.91	0.0108
Oats	1.3	0.92	0.007
Rye	1.6	0.90	0.0048
Millet	1.4	0.89	0.007
Rice	1.4	0.91	0.0072

Note: For the derivation of activity data for nitrogen-fixing crop production, the IPCC default nitrogen content of aboveground biomass (3 percent) was used.

Step 2: Estimate Direct N_2O Emissions from Managed Soils Due to Nitrogen Additions and Cultivation of Histosols

In this step, N_2O emissions were calculated for each of two parts (direct N_2O emissions due to nitrogen additions and direct N_2O emissions due to histosol cultivation), which were then summed to yield total direct N_2O emissions from managed soils (Table L-7).

Step 2a. Direct N_2O Emissions Due to Nitrogen Additions.

To estimate these emissions, the amounts of nitrogen applied were each reduced by the IPCC default fraction of nitrogen that is assumed to volatilize, the unvolatilized amounts were then summed, and the total unvolatilized nitrogen was multiplied by the IPCC default emission factor of 0.0125 kg N_2O-N/kg Nitrogen (IPCC/UNEP/OECD/IEA 1997). The volatilization assumptions are described below.

- *Application of synthetic and organic commercial fertilizer:* The total amounts of nitrogen applied in the form of synthetic commercial fertilizers and non-manure/non-sewage organic commercial fertilizers were reduced by 10 percent and 20 percent, respectively, to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of livestock manure:* The total amount of livestock manure nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of sewage sludge:* The total amount of sewage sludge nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997, IPCC 2000).
- *Production of nitrogen-fixing crops:* None of the nitrogen from the aboveground biomass of nitrogen-fixing crops was assumed to volatilize.
- *Application of crop residue:* None of the nitrogen in applied crop residue was assumed to volatilize.

Step 2b. Direct N_2O Emissions Due to Cultivation of Histosols.

To estimate annual N_2O emissions from histosol cultivation, the histosol areas were multiplied by the IPCC default emission factor for temperate soils (8 kg N_2O-N/ha cultivated; IPCC 2000).[8]

Step 3: Estimate Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

To estimate direct N_2O emissions from soils due to the deposition of pasture, range, and paddock manure, the total nitrogen excreted by these animals was multiplied by the IPCC default emission factor (0.02 kg N_2O-N/kg N excreted) (see Table L-8).

Step 4: Estimate Indirect N_2O Emissions Induced by Applications of Nitrogen

In this step, N_2O emissions were calculated for each of two parts (indirect N_2O emissions due to volatilization of applied nitrogen and indirect N_2O emissions due to leaching and runoff of applied nitrogen) which were then summed to yield total direct N_2O emissions from managed soils.

Step 4a. Indirect Emissions Due to Volatilization.

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen produced, were each multiplied by the IPCC default fraction of nitrogen that is assumed to volatilize to NH_3 and NO_x (10 percent for synthetic fertilizer nitrogen; and 20 percent for nitrogen in organic fertilizer, sewage sludge, and livestock manure). Next, the volatilized amounts of nitrogen were summed, and then the total volatilized nitrogen was multiplied by the IPCC default emission factor of 0.01 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table L-9.

Step 4b. Indirect Emissions Due to Leaching and Runoff.

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen produced, were each multiplied by the IPCC default fraction of nitrogen that is assumed to leach and runoff (30 percent for all nitrogen). Next, the leached/runoff amounts of nitrogen were summed, and then the total nitrogen was multiplied by the IPCC default emission factor of 0.025 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table L-9.

Table L-7: Direct N_2O Emissions from Managed Soils (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Commercial Fertilizers*	55	56	57	59	61	59	61	61	61	62
Livestock Manure	13	13	13	13	13	13	13	14	14	14
Sewage Sludge	1	1	1	1	1	1	1	1	1	1
Nitrogen Fixation	59	60	61	57	66	62	64	68	69	68
Crop Residue	23	23	26	21	28	23	27	29	29	28
Histosol Cultivation	4	4	4	4	4	4	4	4	4	4
Total	**154**	**156**	**162**	**155**	**174**	**163**	**170**	**177**	**178**	**177**

Note: Totals may not sum due to independent rounding.
* These data do not include sewage sludge and livestock manure used as commercial fertilizers, to avoid double counting.

[8] Part of the total U.S. cultivated histosol area is in subtropical regions. These areas should probably be assigned a higher emission factor. This issue will be researched in future U.S. Inventories.

Table L-8: Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure (Tg CO_2 Eq.)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	35	35	36	37	38	39	39	38	37	37
Dairy Cows	2	2	2	2	2	1	1	1	1	1
Swine	+	1	1	+	+	+	+	+	+	+
Sheep	+	+	+	+	+	+	+	+	+	+
Goats	+	+	+	+	+	+	+	+	+	+
Poultry	+	+	+	+	+	+	+	+	+	+
Horses	2	2	3	3	3	3	3	3	3	3
Total	**41**	**41**	**42**	**42**	**43**	**44**	**44**	**43**	**42**	**41**

+ Less than 0.5 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Table L-9: Indirect N_2O Emissions (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Volatil. & Atm. Deposition	12	12	12	12	13	12	13	13	13	13
Comm. Fertilizers	5	5	5	5	5	5	5	5	5	5
Animal Manure	7	7	7	7	7	7	7	7	7	7
Sewage Sludge	+	+	+	+	+	+	+	+	+	+
Surface Leaching & Runoff	62	63	64	66	68	67	68	68	68	68
Comm. Fertilizers	37	38	38	39	41	39	41	41	41	41
Animal Manure	25	25	26	26	26	27	27	26	26	26
Sewage Sludge	+	+	+	+	+	1	1	1	1	1
Total	**74**	**75**	**76**	**78**	**80**	**79**	**81**	**80**	**80**	**80**

+ Less than 0.5 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.